National Aeronautics and
Space Administration

Space Technology Mission Directorate

Technology Demonstration Missions Program

NAC TI&E Committee Meeting Briefing

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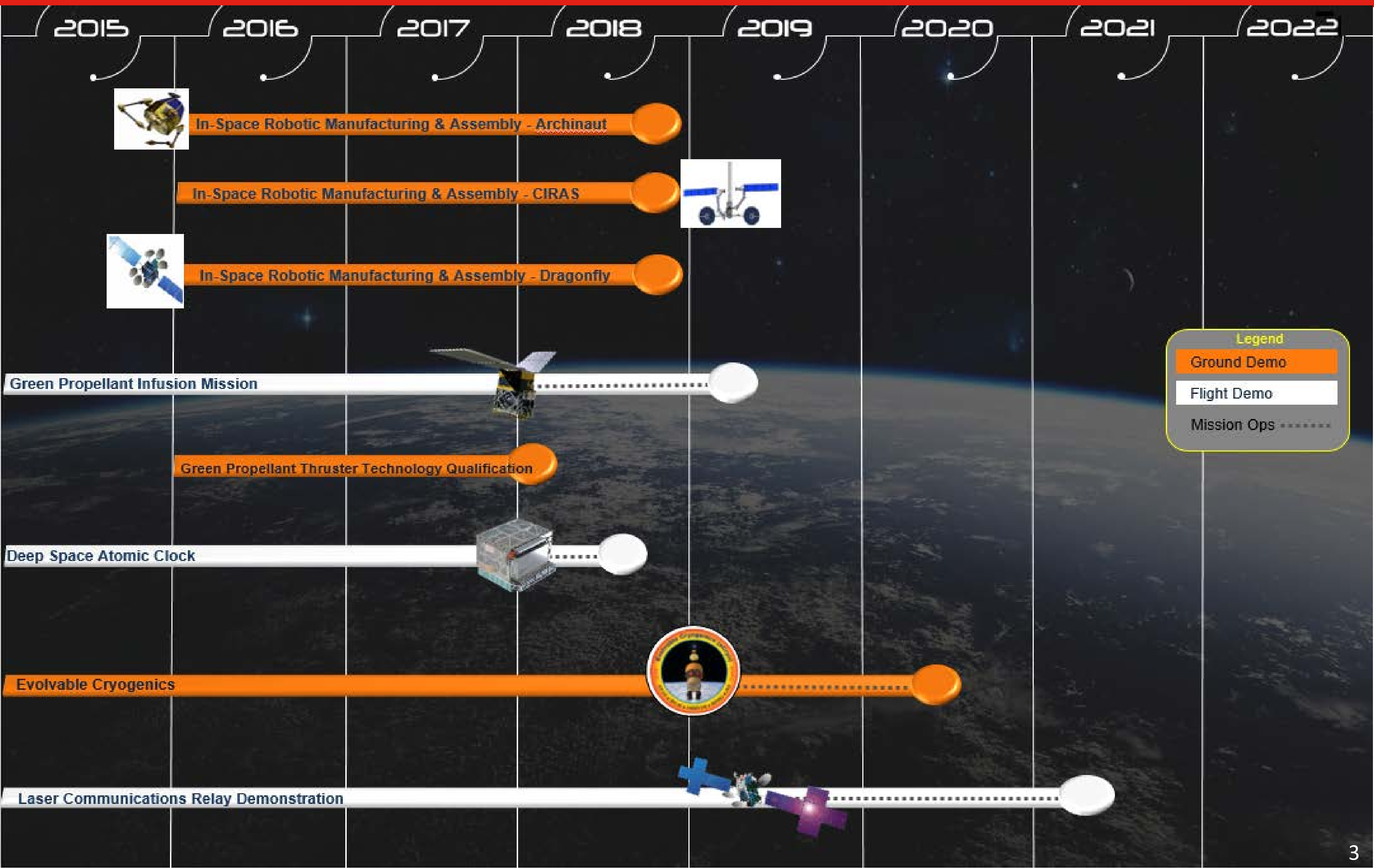
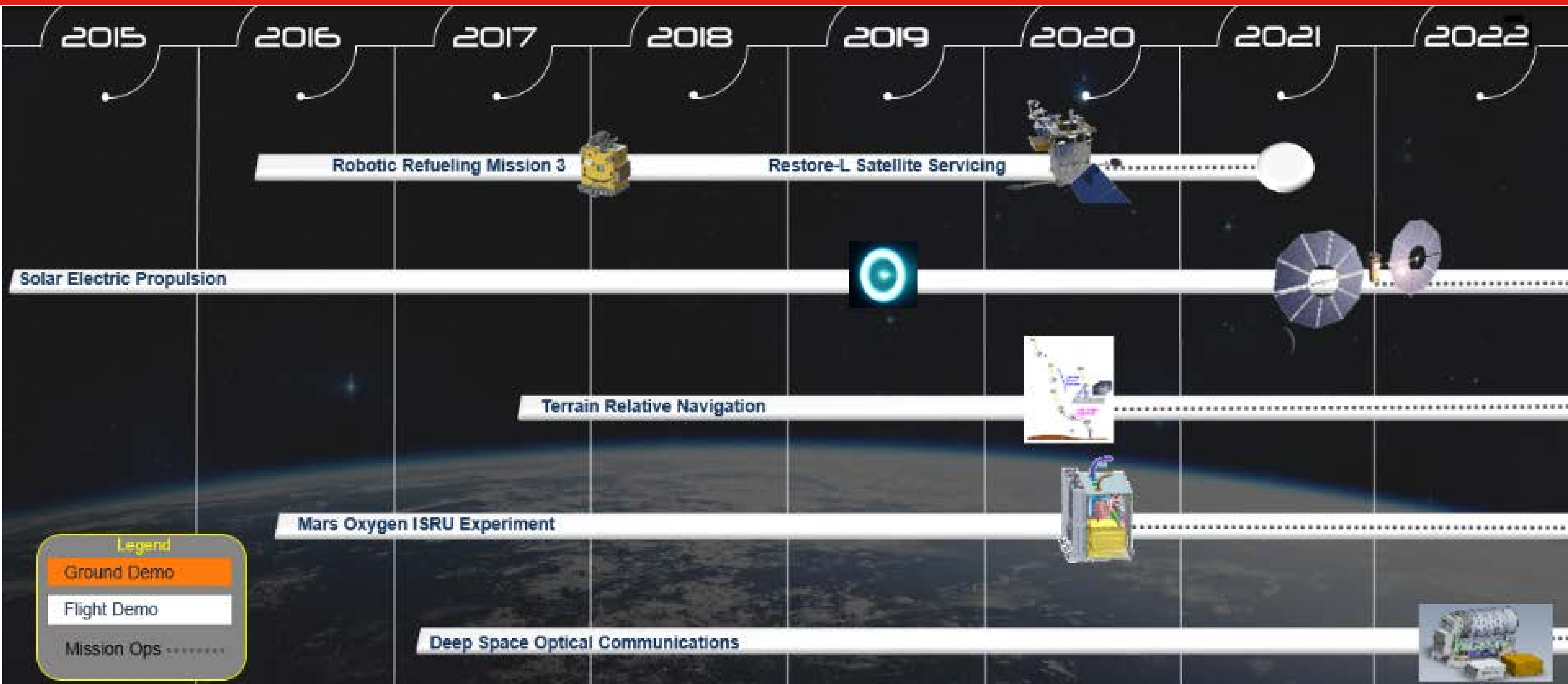
Agenda

- **Technology Demonstration Missions (TDM) Program Overview**
  - Portfolio at a Glance
- **In-Space Robotic Manufacturing and Assembly (IRMA) Update**
- **Future Potential TDM Projects**
  - High Mass Entry, Descent and Landing (EDL)
  - eCryo/Cryogenic Fluid Management (CFM)
  - Direct Exoplanet Imaging
  - Kilopower II

TDM Portfolio at a Glance



TDM Portfolio at a Glance



TDM Goal:

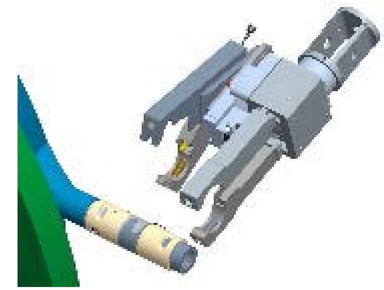
Bridge the gap between development and mission infusion by maturing crosscutting and system-level technologies through demonstration in relevant operational environments

In-Space Robotic Manufacturing and Assembly (IRMA) Update

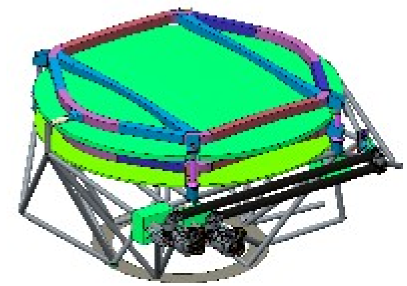
Space Systems Loral (SSL) Dragonfly

Vision:
– *On Orbit Robotic Installation and Reconfiguration of Large Solid Radio Frequency Reflectors.*

Objectives:
– *Demonstrate effective stowage techniques for larger than traditional solid reflectors into a launch.*
– *Demonstrate assembly interfaces originally designed for EVA operations can be modified for use robotically.*
– *Demonstrate assembly joints and additively manufactured antenna support structures meet extremely high frequency antenna performance requirements.*
– *Demonstrate a feasible Con-Ops for augmenting an existing Geostationary Earth Orbit (GEO) Commercial Satellite.*


Gripper concept and auto-lock assembly joint

- Conducted a System Requirements Review to identify and document mission level requirements and the flow down of requirements to mission components, preliminary verification and validation approach and program risks and mitigation strategies.
- Conducted a detailed Test Readiness Review to assess preparations for the Robotic Reflector Assembly Demonstration, including test plan, test objectives and test hardware readiness.
- The Robotic Reflector Assembly Demonstration is scheduled for August 2017.
- Option Period will consist of a Requirements/Verification Plan Review, Performance and Interface Requirements Review, Environmental Testing and a Hardware Design Review of the Assembly Interface and Robot Arm End Effector (Feb-Aug 2018).
- The Option Period will culminate in Robotic Assembly System Mission Concept Review (Aug 2018).


Condensed reflector stowage concept


An ultra-lightweight robot assembles a large reflector on a Communication satellite in GEO

Made In Space (MIS) Archinaut

Vision:

– *System that is able to robotically create spacecraft or extremely large structures in space which reduces spacecraft cost, reduces the limitations rocket launch places on spacecraft design (launch loads and volumes), and removes astronauts from harm's way.*

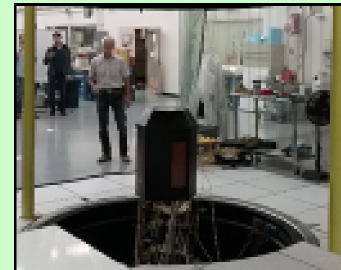
Objectives:

– *Demonstrate extended structure additive manufacturing of structures in a relevant environment using Extended Structure Additive Manufacturing Machine (ESAMM).*
– *Demonstrate additive manufacturing and assembly of structures in a relevant environment using Ground-Based Manufacturing and Assembly System Hardware (GBMASH).*
– *Evaluate part quality through mechanical and structural testing.*

- Completed analysis and testing to down select additive manufacturing materials and structures for further development.
- Conducted a Preliminary Design Review (PDR) for the GBMASH.
- Conducted extensive additive manufacturing demonstration in a simulated space environment (thermal-vacuum) using the ESAMM.
- Detailed materials and structure characterization testing of ESAMM parts is underway.
- Option period will consist of GBMASH Critical Design Review (Jan 2018), Test Readiness Review (Apr 2018), extended GBMASH testing (May-Jun 2018) followed by materials/structure characterization testing (Jun 2018).

Phase I

ESAMM



Thermal-Vacuum Prototype

GBMASH

Phase II

Dilo: Flight Demo Mission Concept

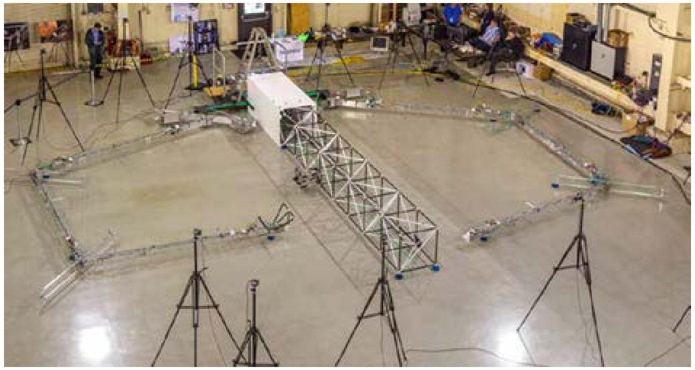
Orbital ATK CIRAS

Vision:

– *A robotic assembly, repair, maintenance and refurbishment capability to enable repurposing of spacecraft modules.*

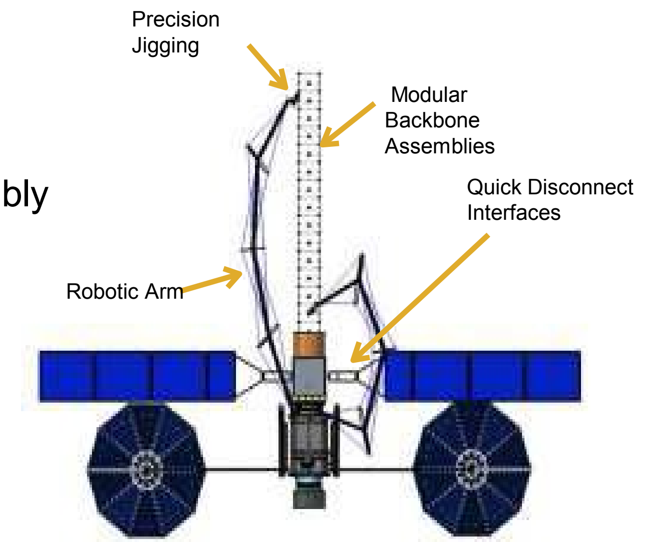
Objectives:

– *Demonstrate robotic reversible joining methods for mechanical and electrical connections.*
– *Develop a feasible concept to validate space assembly geometries.*
– *Demonstrate repeatable module to module interfaces for in-space structural assembly.*



TALISMAN Robot Arms

- Conducted a Mission Concept Review to affirm mission objectives and concept for meeting objectives.
- Conducted Electron Beam Precision Welding Demonstration to assess accuracy/alignment requirements for on-orbit applications.
- Conducted a System Requirements Review to identify functional and performance requirements for the robot arm, end effector, control electronics and truss and solar array interfaces to meet mission requirements.
- Conducted demonstrations of the NASA Intelligent Jigging and Assembly Robot (NINJAR) and of the Electron Beam Welding simple joint.
- Option Period will consist of assembly, integration and system ground demonstration of the Tension Actuated Long Reach in Space Manipulator (TALISMAN) robotic arm and NINJAR (Apr 2018).
- Conduct a detailed Technology Readiness Review to fully document the TRL advancement (May 2018).



Path to Future Flight Demo IRMA

- All project teams (MIS, Orbital ATK, SSL) are making good progress and appear to be on-track to achieving all requirements contained in the scope of work; the teams are making the required deliverables on schedule.
- The TDM Program led an assessment of the FY17 base period. Based on the results of the assessments performed and assuming that budgetary resources are available, the assessment team recommended that all 3 of the IRMA projects be approved to perform the Option Period of the current contracts.
- STMD granted approval to the TDM Program Office to execute the contract option for all three projects.
- The current Phase 1 contracts (base period and option period) will conclude in October 2018. A Technology Readiness Assessment will be conducted at the end of Phase 1.
- A Request for Information (RFI) will most likely be released to gather input from industry and inform the procurement process for a potential flight demonstration project utilizing a Public Private Partnership (PPP). An In-Space Robotic Manufacturing and Assembly roadmapping exercise is underway and would also inform the path forward for flight demonstration planning.

High Mass Entry, Descent and Landing

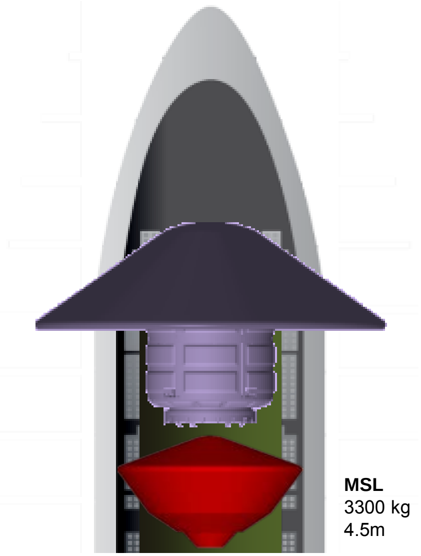
(HIAD - Hypersonic Inflatable Aerodynamic Decelerator)

What is HIAD?

A Hypersonic Inflatable Aerodynamic Decelerator (HIAD) is a deployable aeroshell consisting of an Inflatable Structure (IS) that maintains shape during atmospheric flight, and a Flexible Thermal Protection System (F-TPS) employed to protect the entry vehicle through hypersonic atmospheric entry.

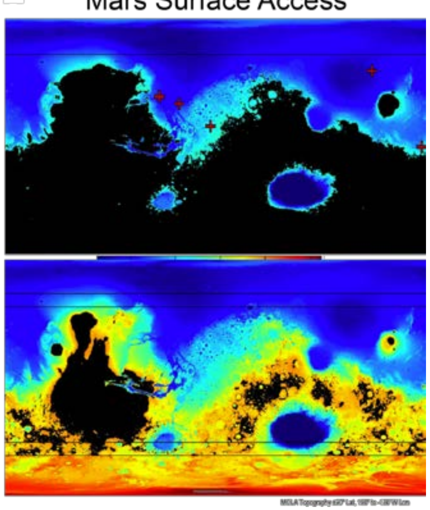
Executive Summary
Why HIAD?

- Entry mass at Mars (and other destinations with atmospheres) is limited by launch vehicle fairing size.
- Increased drag area is needed for higher mass and/or higher altitude landings.
- Inflatable heatshield technology
  - Allows payloads to use the full diameter of the launch fairing.
  - Can be stowed into available volume and somewhat irregular shapes.
  - Deploys a large aeroshell before atmospheric interface.
  - Enables landing more payload mass and/or at higher altitude.



Rigid aeroshells limited to low altitude sites (blue)

Inflatables allow access to southern highlands



Future Potential Flight Demo HIAD-TDM

- **Schedule**: Proposed FY18 – 21 period of performance as potential Public Private Partnership (PPP).
- **Technical**: Perform a high-energy flight test of a 6-meter HIAD.
- **Near Term:** Strong commercial technology pull
  - Commercial Launch companies want to employ rocket stage reuse and improve the capability to return mass from low Earth orbit; they recognize the mass efficiency of aerodynamic decelerators.
  - Industry objectives justify FY18 start and they also desire compression on NASA's nominal 36 months schedule.
- **Long Term:** Earth orbital reentry introduces HIAD technology to a design-reference atmospheric entry environment.
  - HIAD-TDM will test HIAD technology at Mars-relevant heating environment, and at twice the diameter of the Inflatable Reentry Vehicle Experiment (IRVE-3), which was a 3m configuration sounding rocket demonstration in 2012.
  - Opportunity for Mid-Air Recovery (MAR), and post-entry examination, of aeroshell
  - 6m scale is ~½ scale for both rocket stage recovery and Mars round-trip technology demonstration; 1/3 scale for human Mars payloads

Cryogenic Fluid Management (CFM)

eCryo Status

Objective: Develop, integrate, and validate cryogenic fluid management (CFM) technologies at a scale relevant to and meeting the mission needs for NASA missions and SLS/Stages

- **Radio Frequency Mass Gauge (RFMG):**
  - Delivered Flight Avionics and Antennas to RRM3 Project for ISS demo launching on SpaceX-14.
- **Improved Fundamental Understanding of Super Insulation (IFUSI):**
  - Completed Repeatability Testing of Multilayer Insulation (MLI).
  - Completed MLI seams and attachment testing informing Structural Heat Intercept Insulation Vibration Evaluation Ring (SHIIVER) design.
- **Development & Validation of Analysis Tools (DVAT):**
  - Signed Joint Understanding (JU) Agreement with JAXA to exchange cryogenic test data for model validation.
- **Integrated Vehicle Fluids (IVF):**
  - Completed testing of United Launch Alliance’s IVF hardware as proof of concept.
  - Submitted the Final Report of the 3 phases of testing which included an assessment of the feasibility for incorporating into SLS.
- **Structural Heat Intercept Insulation Vibration Evaluation Rig (SHIIVER):**
  - Finalized design and started fabrication of several key support hardware elements (Support Stand, Aft Skirt, Forward Skirt).
  - SHIIVER tank scheduled to be delivered by the end of July.

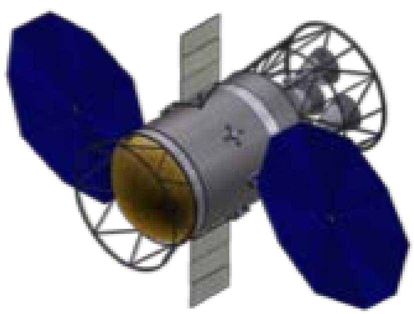
RFMG Avionics

SHIIVER Tank

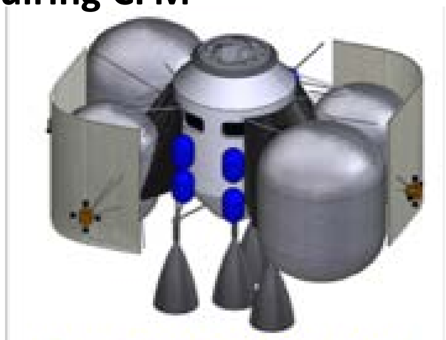
CFM Roadmapping Activity

- **Cryogenic Fluid Management (CFM) Roadmap:**
  - Team performed a CFM Roadmap technology assessment for architectures identified by the Mars Study Capabilities Team.
  - Assessed 25 CFM technologies against potential Mars architectures for future CFM Demonstrations.
  - The CFM Roadmap identified technologies requiring flight demonstrations for infusion into future deep space missions.

Potential Mars Elements Requiring CFM



Methane Cryogenic Propulsion Stage (MCPS)



Mars Ascent Vehicle (MAV)

Nuclear Thermal Propulsion (NTP)

Mars Lander

Future Potential Flight Demo CFM

- **Schedule:** FY18 (possible Broad Agency Announcement Studies) or FY19 (possible project start).
- **Technical: CFM RFI issued on July 12 with 30 day response period.**
  - The intent of the RFI is to establish a public-private partnership with industry for the further development of CFM technologies in the functional areas of: Storage, pressure control, transfer, and mass gauging. While NASA is primarily concerned with CFM applications in the below areas, the RFI does request input from industry on applications that NASA may not be currently pursuing.
    - Nuclear thermal propulsion and other chemical in-space propulsion systems.
    - Reaction Control Systems (RCS) and Main Propulsion Stage (MPS) operations during planetary ascent and descent flight phases.
    - In-Situ Resources Utilization (ISRU) based production systems.
    - Propellant depots for refueling in-space transportation systems.
    - Ground-based cryogenic propellant storage and transfer for autonomous fueling of launch vehicles.

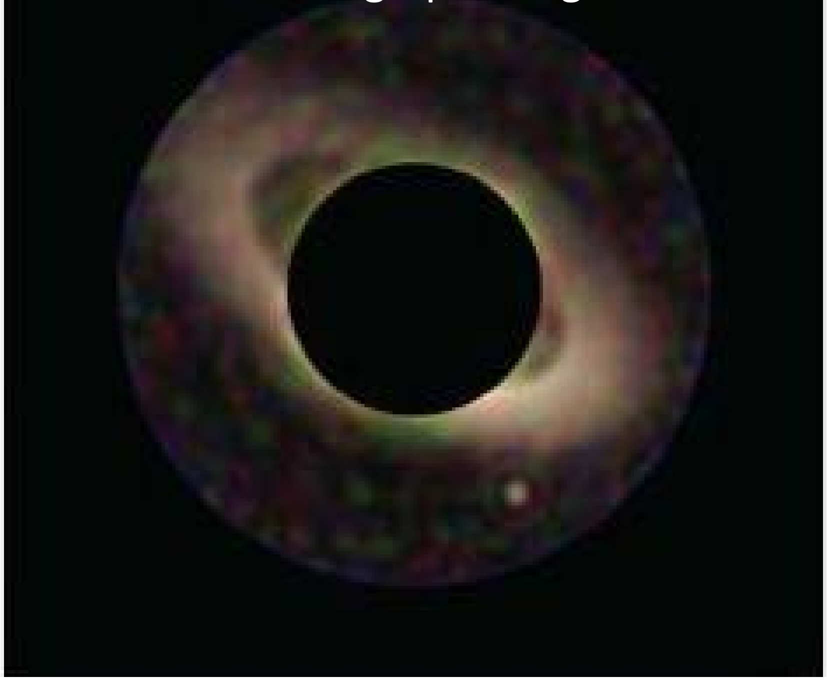
Direct Exoplanet Imaging (Coronagraph)

Why Coronagraph?

- **Wide-Field Infrared Survey Telescope (WFIRST) presents a unique opportunity to achieve significant breakthroughs in the search for life**
  - 1000x improvement on state-of-the-art in coronagraphy
  - First-ever images and spectra from mature planets around sun-like stars
  - Far-lower cost than a dedicated flight demo mission

- **Coronagraph is an ideal partnership opportunity for STMD and SMD**
  - Cross-cutting technology
  - Enormous public impact

Simulated WFIRST Hybrid Lyot Coronagraph Image



https://science.nasa.gov/technology/technology-stories/wfirst-coronograph

Executive Summary

- **STMD/SMD investment in the past 4 years has brought coronagraph technology to TRL 5 with demonstrated performance 100X better than state of the art.**
  - Demonstrated raw contrast of ~10-8 in a dynamic environment with broadband light!
- **Current space-based (HST, JWST) and ground-based (GPI) coronagraphs are ~3 orders of magnitude worse than required for exoplanet direct imaging and characterization.**
  - 2010 Astrophysics Decadal Survey ranked New Worlds Technology Program as top medium-scale priority for space projects.
- **An STMD/SMD partnership would bring the technology to TRL 9 with performance of ~4 x 10-9, enabling breakthrough results:**
  - First optical images of ~10 known RV (radial-velocity) extrasolar giant planets (EGPs) orbiting mature Sun-like stars.
  - First reflected (albedo) spectra a few of these, probing their atmospheric chemistry (H_2O, CH_4, NH_3, etc.) and providing unique constraints on their evolution, aerosol and cloud properties.
  - Spectroscopy of exoplanets is the only method to detect signatures of life in exoplanet atmospheres.
  - Humanity closer to answering the question “Are We Alone?”

WFIRST Coronagraph Team

- WFIRST is managed by GSFC
  - WFIRST Project Manager: Kevin Grady
  - WFIRST Project Scientist: Jeff Kruk (acting)
  - WFIRST Payload Manager: Dave Content
- Coronagraph instrument is managed by JPL
  - JPL Instrument Project Manager: Peg Frerking
  - JPL Instrument Deputy Project Manager: Feng Zhao
  - JPL WFIRST Project Scientist: Jason Rhodes
  - Instrument Systems Engineer: Ilya Poberezhskiy
- Other coronagraph partner institutions:
  - NASA centers:
    - GSFC (responsible for integral field spectrograph)
  - Industry:
    - Northrup Grumman Xinetics (deformable mirror)
    - e2v (Electron Multiplying CCD – EMCCD)
    - Harris (coronagraph tertiary and collimator assembly)
  - Science Investigations Teams (SIT):
    - SIT #1 PI: Bruce Macintosh, Stanford University
    - SIT #2 PI: Maggie Turnbull, SETI Institute
  - Coronagraph Adjutant Scientist (CAS):
    - Jeremy Kasdin, Princeton University
  - Science Center:
    - IPAC/Caltech, STScI
  - Potential International Partners:
    - ESA, JAXA (discussions underway)

Future Potential Flight Demo Coronagraph

- **Schedule:** Potential FY19 start through FY23 (assuming WFIRST 2025 launch date).
- **Technical: Matured this to TRL 5 in FY17; Flight tech demo to bring as a Class C Payload on WFIRST.**
- **Notable Items:**
  - SMD high priority.
  - TDM/SMD investment would bring TRL to 9.
  - Proposed STMD contribution is phased to cover the period of flight hardware development, assuming the 2025 launch date, with a lower level of contribution post-delivery through Phase E for continued enhancement of control modes and algorithm development.
  - The baseline demo would develop the following cross-cutting technologies: space telescope pointing/jitter control; space-qualified deformable mirrors; rad hard low-noise focal plane arrays and readout electronics; micro and nano optical element fabrication techniques; innovative algorithms for space telescope wavefront error estimation; optical analysis tools.

Kilopower II

What is Kilopower?

- Approach for long-duration, sun-independent electric power for space or extra-terrestrial surfaces.
  - Produces from 1 to 10 kilowatts, continuously for 10 years or more.
  - Weighs about 400 kg at 1 kW or 1500 kg at 10 kW, for complete system.
  - Uses solid, cast uranium-235 reactor core, about the size of a paper towel roll.
  - Transfers reactor heat with passive sodium heat pipes.
  - Converts heat to electricity with high efficiency Stirling engines.
  - Leverages current DOE fuel production processes and abundant material supply from dismantled nuclear weapons.
  - Launches as a radiologically benign, non-operating (cold) payload.

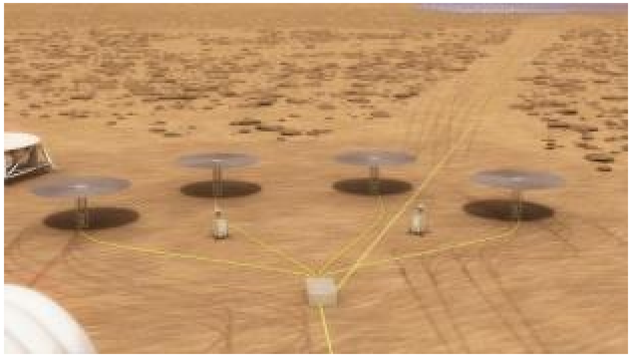
- Represents NASA’s first attempt at building and testing a space reactor since the 1960s SNAP Program.

Possible Kilopower Applications

- Government Missions:
  - Human Mars surface missions
  - Lunar surface operations
  - Planetary orbiters and landers: Europa, Titan, Enceladus, Neptune, Pluto, etc.
  - Planetary nuclear electric propulsion: Small Bodies, Ocean Worlds, Interstellar, etc.
  - Defense satellites
- Commercial Missions:
  - Space mining
  - Lunar/Mars settlements
  - Power beaming
  - High-rate communications
- Terrestrial Missions:
  - Military Forward Operating Bases
  - Unmanned Underwater Vehicles

- Power uses: drilling, melting, heating, refrigeration, sample collection, material processing, manufacturing, video, radar, laser, EP, telecomm, rover recharging.

Mars Surface Operations



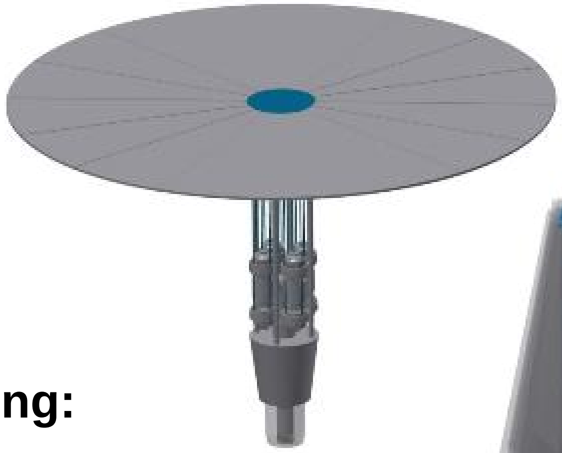
- **No off-the-shelf options exist to power long-term human surface missions on Mars**
  - Power systems used on previous robotic missions (e.g. MSL, Phoenix) will not suffice.

- **Stationary power needs:**
  - Up to 40 kW day/night continuous power.
  - Power for ISRU propellant production (pre-crew arrival).
  - Power for landers, habitats, life support, rover recharging (during crew operations).
  - Technology options: Nuclear Fission or Photovoltaics (PV) with Energy Storage.
  - Need compact stowage, robotic deployment, survivable for multiple crew campaigns (>10 yrs), long distance power distribution (1-2 km), and contingency options for dust storms.
  - Potential mid/late 2020s Mars EDL-ISRU-Power Tech Demo Lander Mission (5 to 10 kW).

- **Mars/Moon environment comparison:**
  - Mars environment challenges include: 3/8th gravity, 1/3rd solar flux, >12 hour night, CO_2 atmosphere, dust storms, wind loads, 170 to 270K temperature cycles.
  - Moon: 1/6th gravity, 354 hour night, vacuum, dust, 100 to 370K temperature cycles.

Proposed Follow-on: Kilopower II

- **High-fidelity TDM Ground Demo being considered in near-term budget horizon**
  - Contingent on successful TRL 5 test under Game Changing Development (GCD) Project and funding availability.
- **Potential Project content to include the following:**
  - Mars system scalability study (up to 10 kWe).
  - Detailed reactor design using validated computer models.
  - Experiments to demonstrate in-core heat pipe integration.
  - Contracts to design/build/test kilowatt-class power conversion units.
  - Culminates in high-fidelity system ground test operated in simulated Mars surface environment (potentially in combination with an ISRU ground test).
  - Includes studies to evaluate nuclear launch safety and crew radiation safety.
  - Includes option for possible nuclear flight demonstration.



Deployed

Stowed

Technology Drives Innovation

www.nasa.gov/spacetech